Sediment Erosion and Redistribution in Fine-Grained Shelf Environments

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LONG-TERM GOALS

My long-term goal within the EuroSTRATAFORM program has been to increase our ability to predict sediment transport in fine-grained regions of the continental shelf through field work and application and further development of models at the Adriatic and Gulf of Lions EuroSTRATAFORM sites. Testing and extending our conceptual and numerical sediment transport models at these sites is an important goal of the EuroSTRATAFORM shelf process studies.

OBJECTIVES

The broad objectives of this project are to 1) measure along-shelf, across-shelf and temporal variations in critical shear stress and entrainment rates; 2) compare suspended sediment concentrations measured by bottom tripod with values calculated using measured entrainment rates; and 3) explore the implications of spatial variations in critical shear stress on cross-shelf sediment transport and deposition. During FY07 I was given a no-cost extension in order to 1) serve as lead guest editor of a special issue of Continental Shelf Research devoted to recent studies of hydrodynamics and sediment dynamics in the Gulf of Lions (Xavier Durrieu de Madron and Pere Puig are co-editors); and 2) complete analysis of erosion measurements made in the Gulf of Lions during the EuroSTRATAFORM program.

APPROACH

Our approach for measuring erosion was to use an erosion chamber fit onto a core tube to make shipboard measurements of critical shear stress and entrainment rates of freshly collected seabed sediment. The results were then used to develop expressions for the entrainment rates of fine-grained sediment at the measurement sites that are then tested against near-bed field data. In this last phase, detailed modeling of the erosion tests is being carried out to investigate the specific effects of grain size sorting on erosion rates.

WORK COMPLETED

1. Continental Shelf Research (CSR) accepted the proposal for a special issue on the Gulf of Lions that I submitted on behalf of the North American and European participants working in the Gulf of Lions as part of EuroSTRATAFORM and related projects.

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2. All papers for the special issue have been submitted and most have been peer reviewed and returned to authors for revision. Puig, Durrieu de Madron and I will be writing an introductory paper for the special issue this fall. We hope to send the full set of papers to CSR close to the end of the year.

3. I was a co-author of a paper submitted to the special issue of CSR and lead author of a paper submitted to a special issue of Computers and Geosciences edited by James Syvitski which is focused on EuroSTRATAFORM and related studies.

4. Analysis of size selectivity of erosion at sites characterized by cohesive and largely non-cohesive erosion behavior is underway. The results of this work, combined with those of complementary laboratory experiments in progress with separate ONR funding, will be presented at the 2008 Ocean Sciences meeting.

RESULTS

Special Issue of Continental Shelf Research: All papers submitted to a special issue of Continental Shelf Research (CSR) on recent studies of flow and sediment dispersal in the Gulf of Lions co-edited by Wiberg, Puig, and Durrieu de Madron are listed in Table 1. Submission and review are staying close to the proposed schedule. All but four have completed peer review and are in the process of being revised. An introductory paper will be written once all of the papers have been through review. These papers span a range of approaches and time scales but share a focus on the processes responsible for sediment input, dispersal, and export from the Gulf of Lions shelf and canyon system, particularly in the south-western Gulf. We hope to submit the full set of papers to CSR near the end of the year.

Table 1: Papers submitted to the Gulf of Lions special issue of Continental Shelf Research

Bourrin, F., P.L. Friend, C.L. Amos, C.E.L. Thompson, E. Manca, X. Durrieu de Madron, and A. Palanques	An oceanic flood in a microtidal, storm dominated basin: the Têt, Gulf of Lions (NW Mediterranean, France)
Harmelin-Vivien, M., V. Loizeau, C. Mellon, B. Beker, D. Arlhac, X. Phillipon, and C. Salen	Comparison of C and N stable isotope ratios between surface particular organic matter and phytoplankton in the Gulf of Lions (NW Mediterranean)
Puig, P., A. Palanques, D. Orange, G. Lastras, M. Canals	Dense shelf water cascading and furrows formation in the Cap de Creus submarine canyon, northwestern Mediterranean margin
Bonnin, J., Heussner, S., A. Calafat, J. Fabres, A. Palanques, X. Durrieu de Madron, M. Canals, P. Puig, J. Avril, and N. Delsaut	Effect of storms on temporal and spatial variability of downward particle fluxes across canyons of the Gulf of Lions (NW Mediterranean)
Ferre, B., X. Durrieu de Madron, C. Estournel, C. Ulses and G. Le Corre	Impact of natural (waves and currents) and anthropogenic (trawl) resuspension on the export of particulate matter to the open ocean. Application to the Gulf of Lion (NW Mediterranean)
Andre, G.I. P. Garreau and P. Fraunié	Mesoscale slope current variability in the Gulf of Lions. Interpretation of in-situ measurements using a tridimensional model.

Fabres, J., Tesi, T., Velez, J., Batista, F., Lee, C., Calafat, A., Heussner, S., Miserocchi, S., Palanques, A.	Seasonal and event controlled export of fresh organic matter towards the Gulf of Lions continental slope
DeGeest, A.L., B.L.Mullenbach, P. Puig, C.A. Nittrouer, and T.M. Drexler, Orange, D.L., Durrieu de Madron, X.	Sediment accumulation in the western Gulf of Lions, France: The role of Cap de Creus Canyon in linking shelf and slope sediment dispersal systems
Ogston, A.S., T.M. Drexler, and P. Puig	Sediment delivery, resuspension, and transport characterizing canyon environments in the southwest Gulf of Lions
Bourrin, F., X. Durrieu de Madron, S. Heussner, C. Estournel	Sediment erosion by severe dense water flow on the Gulf of Lion shelf
Palanques, A., J. Guillén, P. Puig and X. Durrieu de Madron	Storm-driven shelf to canyon sediment transport in the southwestern end of the Gulf of Lions.
Drexler, T.M.and C.A. Nittrouer	Stratigraphic signatures due to flood deposition near the Rhône River; Gulf of Lions, Northwest Mediterranean Sea
Ulses, C., C. Estournel., A. Palanques and X. Durrieu de Madron	Suspended sediment impact in the Gulf of Lion (NW Mediterranean): Impact of extreme storms and floods
Law, BA., P.S. Hill, T.G. Milligan, K.J. Curran, P.L. Wiberg, R.A. Wheatcroft	The effect of grain-size on the erodibility of bottom sediments
Dufois, F., P. Garreau, O. LeHir, P. Forget	Wave and current-induced bottom shear stress distribution in the Gulf of Lions
Herrmann, M., C. Estournel, M. Déqué, P. Marsaleix, F. Sevault, S. Somot	Dense water formation in the Gulf of Lions shelf: impact of atmospheric interannual variability and climate

Analysis of erosion tests: Grain size measurements by Law et al. (in revision) of sediment suspended during our erosion tests in the Gulf of Lions show a very distinct difference in the disaggregated size distribution of sediment eroded from sandy-silt and silt beds. Results show that progressively larger grains were eroded from the bed as shear stress increases on a non-cohesive, sandy silt bed. In contrast, for cohesive beds, all sizes up to medium silt were eroded at essentially the same rate regardless of shear stress.

I am following up these results with detailed modeling of measured erosion time series to better define the differences in erodibility of silty (cohesive) and sandy-silt (largely non-cohesive) sediment and the transition between these two states. The results of forward modeling of erosion tests (Figure 1) illustrate some of the subtleties of interpreting erosion measurements. The top panel of each column shows a time series of cumulative mass eroded based on the erosion equation, $E=M(\tau_b - \tau_{cr})$ where E is erosion rate, M is entrainment coefficient, τ_b is bed shear stress and τ_{cr} is critical shear stress; stress increases every 20 min and M is set to a constant value indicated at the top of each column. The left column corresponds to cohesive sediment with a profile of increasing critical shear stress with depth; the middle column is for non-cohesive sediment of uniform size; the right column is for non-cohesive, non-uniform sediment with an active layer of limited thickness. The second row shows the erosion rate, E, for each case. For the cohesive sediment (left), each step is not quite long enough for E to go to zero before stress increases. For the non-uniform, non-cohesive sediment, the mass eroded is sensitive to the amount of each sediment size available in the active layer (right). The bottom row shows the entrainment coefficient inferred from the time series shown in the middle row. The inferred entrainment rate for the cohesive sediment (bottom left) suggests that entrainment coefficient was variable even though the erosion rate time series was calculated with a constant value of M (=0.0015). This is a consequence of making the assumption that $\tau_b = \tau_{cr}$ at the end of the stress step, whereas the step stopped short of that time. The inferred entrainment rate for the non-cohesive, non-uniform sediment (bottom right) is more like that for cohesive sediment (bottom left) than for uniform, non-cohesive sediment (bottom middle), although the timing is less regular. This is the effect of the active layer limiting availability of each size class. These results are being used to help interpret the erosion test results from the Gulf of Lions, which range from cohesive to largely non-cohesive sediment.

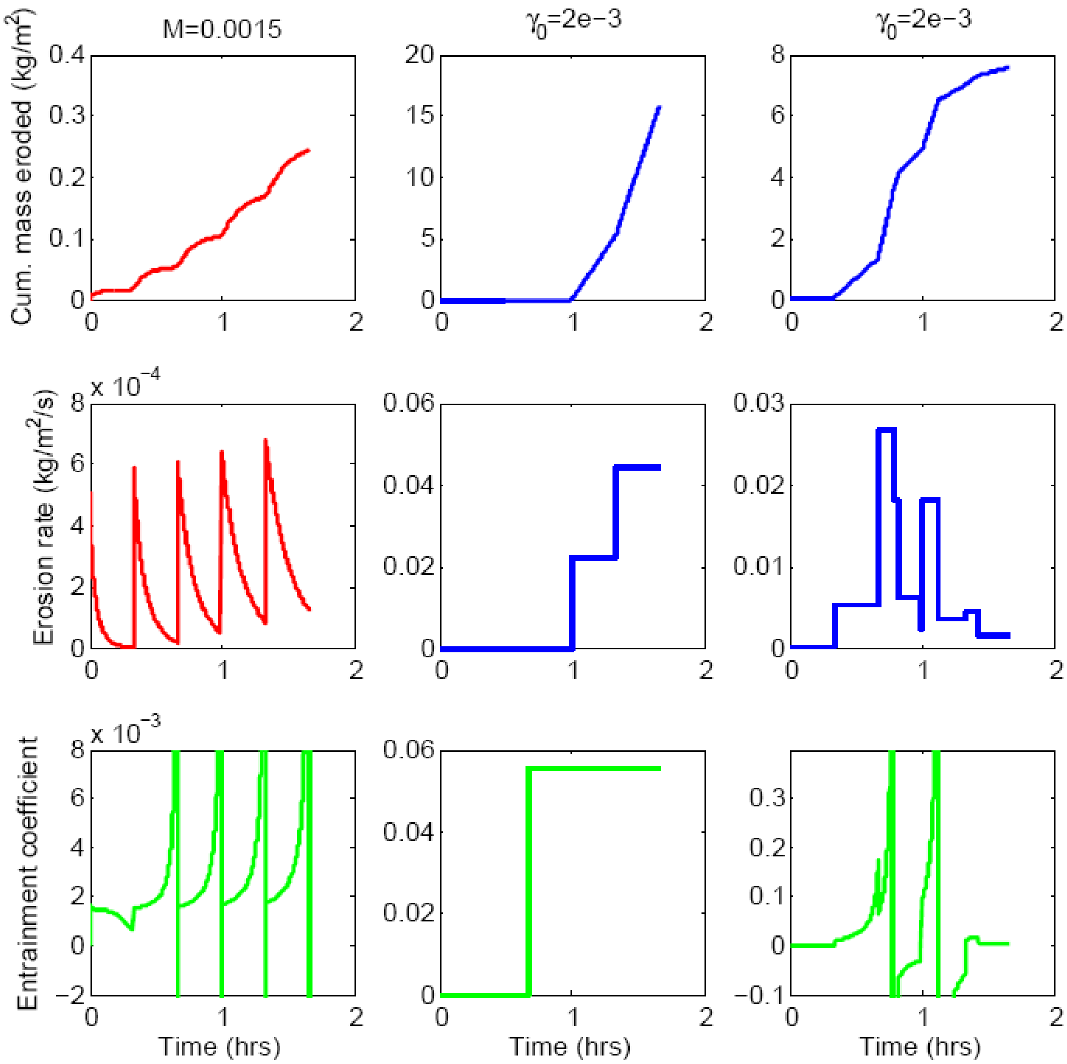

Figure 1. Cumulative mass eroded (top row) and erosion rate (middle row) time series for cohesive (left), non-cohesive, uniform (middle) and non-cohesive, non-uniform (right) sediment; these were calculated using the constant entrainment coefficient listed at the top of each column. The bottom row shows the entrainment coefficient inferred from the erosion time series, indicating variability not present in the actual entrainment coefficient.

Calculating bottom orbital velocity from surface wave parameters: Bottom orbital velocities, a measure of the variance or energy of wave-induced bottom orbital motion at the bed can be calculated in several ways, depending on the available data. We developed a parametric method for estimating bottom orbital velocity from surface wave parameters using a generalized spectral form proposed by Donelan et al. (1985) and compared bottom orbital velocities calculated from near-bed velocity data and measured wave spectra with values estimated from surface wave parameters for sites on the US east and west coasts The results show that bottom orbital velocities calculated from surface wave parameters and a generalized spectrum can be quite accurate except when bimodal waves are present with maximum energy at the higher frequency peak (e.g., Figure 2). These conditions are most likely to occur at times of relatively small bottom orbital velocities, when sediment transport rates are small. The parametric spectral method is particularly useful for calculating spatial fields of bottom orbital velocity from gridded surface wave significant wave height and peak period, such as wave models and hindcasts produce. Calculations of wave-driven sediment transport or other near-bed wave processes will vary depending on the choice of bottom wave velocity statistic, e.g., representative or significant bottom orbital velocity, used to parameterize the effective wave velocity. The results and computer programs (in MATLAB) are provided in Wiberg and Sherwood, in press.

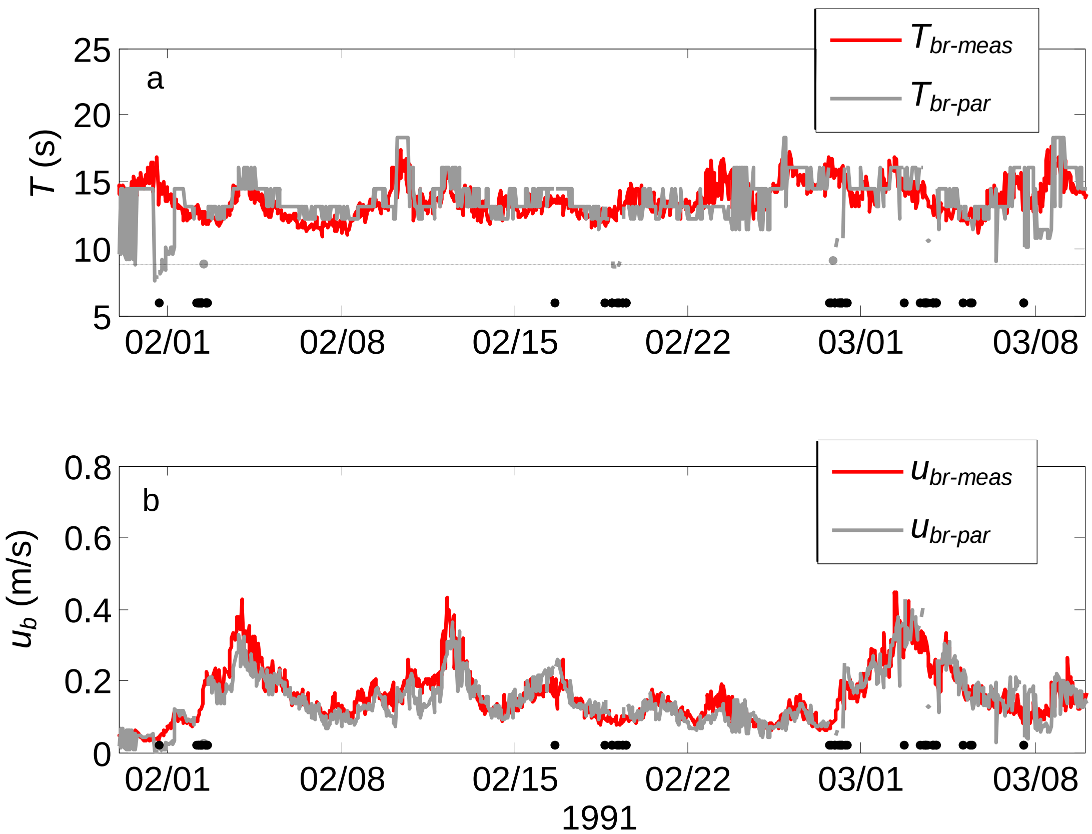

Figure 2. Comparison of bottom wave period, Tbr-par, calculated from the Donelan spectrum with Tbr-meas calculated from Geoprobe near-bed velocity measurements (top). Comparison of bottom orbital velocity, ubr-meas, calculated from Geoprobe near-bed velocity measurements with orbital velocity calculated from the Donelan parametric spectrum, ubr-par. The black dots correspond to times when the wave spectrum was bimodal and calculations using the Donelan spectrum did not converge, indicating that surface wave parameters were inconsistent with this unimodal spectral form.

IMPACT/APPLICATION

Critical shear stress and entrainment rates are among the most poorly constrained parameters in shelf sediment transport calculations. These measurements are improving our ability to specify these important parameters. The field programs in the Adriatic and Gulf of Lions provided near-bed sediment transport measurements against which model calculations made using entrainment rates determined in this study are being tested.

RELATED PROJECTS

The models we are using in this project were developed in the STRATAFORM program.

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